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SCS
NATIONAL
ENGINEERING
HANDBOOK

SECTION 15

IRRIGATION

Chapter 6

CONTOUR-LEVEE IRRIGATION

July 1967

SOIL CONSERVATION SERVICE
UNITED STATES DEPARTMENT OF AGRICULTURE

The Soil Conservation Service National Engineering Handbook is intended primarily for Soil Conservation Service (SCS) engineers. Engineers working in related fields will find much of the information useful to them also.

This handbook is being published in sections, each section dealing with one of the many phases of engineering included in the soil and water conservation program. For easy handling, some of the sections are being published by chapters. Publishing of either sections or chapters is not necessarily in numerical order.

As sections or chapters are published, they will be offered for sale by the Superintendent of Documents, Government Printing Office, Washington, D.C., 20402, at the price shown in the particular handbook.

Section 15 of the handbook, Irrigation, is being published to supply engineers the basic data necessary to plan and maintain efficient conservation practices to provide a permanent irrigated agriculture. Engineering principles and research findings have been screened to give emphasis to the information needed to design, install, and operate irrigation systems on individual farms and groups of farms. Chapter 6, Contour-Levee Irrigation, describes briefly the factors that must be considered in applying contour-levee irrigation to nearly level strips or areas of predetermined size at a rate enough in excess of the intake rate of the soil to permit rapid coverage. Other chapters in this section describe the soil and plant properties that affect the movement, retention, and use of water and provide design criteria, design procedures, and methods of adapting engineering and research data to local irrigation problems. Numerous phases of irrigation engineering are included.

Chapters of Section 15 already published are listed below.

Chapter 1. Soil-Plant-Water Relationships. Price 45 cents.
Chapter 3. Planning Farm Irrigation Systems. Price 60 cents.
Chapter 8. Irrigation Pumping Plants. Price 45 cents.
Chapter 9. Measurement of Irrigation Water. Price 45 cents.
Chapter 11. Sprinkler Irrigation. Price 55 cents.
Chapter 12. Land Leveling. Price 60 cents.

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SCS NATIONAL ENGINEERING HANDBOOK

SECTION 15

IRRIGATION

CHAPTER 6--CONTOUR-LEVEE IRRIGATION

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NOMENCLATURE

A = Area irrigated in acres

E = Field application efficiency in percent

F_g = Gross depth of application in inches

F_n = Net depth of application in inches

f = Time allowed for one complete irrigation in days

h = Daily system operation time in hours

Q = Required irrigation stream in cubic feet per second

q = Required stream size per acre in acre-inches per hour or cubic feet per second per acre

T_n = Time required for the net depth of application (F_n) to infiltrate the soil in minutes

u = Peak-period consumptive-use rate in inches per day

vi = Vertical interval between levees in feet or inches

SCS NATIONAL ENGINEERING HANDBOOK

SECTION 15

IRRIGATION

CHAPTER 6--CONTOUR-LEVEE IRRIGATION

Application Principles

In irrigating by the contour-levee method water is applied to nearly level strips or areas of predetermined size at a rate enough in excess of the intake rate of the soil to permit rapid coverage. Water is retained by small dikes or levees that surround the strips and are constructed longitudinally on the contour. In rice irrigation, each strip is covered with water to a depth that controls weed growth without damaging the rice. This is known as flooding. Water is continuously added to replace water lost through evapotranspiration, deep percolation, and boundary levees. This is called maintaining the flood. For other crops water is kept on the strips until the desired depth has entered the soil. The excess water is then drained off by gravity and used on a similar strip at a lower elevation. This step is called flushing and is repeated often enough to meet water requirements of the crop.

Adaptability

Crops

The contour-levee method has been used for many years for flooding rice fields. It has been adapted to the irrigation of pasture grasses, hay crops, small grains, and some row crops. Row crops irrigated by this method are those that can stand temporary flooding or flushing without damage, namely, cotton, corn, and soybeans. This method is not recommended for irrigating vegetables, tobacco, and other row crops easily damaged by temporary flooding.

Soils

Contour-levee irrigation is adapted to medium- to fine-textured soils having an available water holding capacity of no less than 1.25 inches per foot of depth nor less than 2.5 inches for the root zone depth of the crop being irrigated.

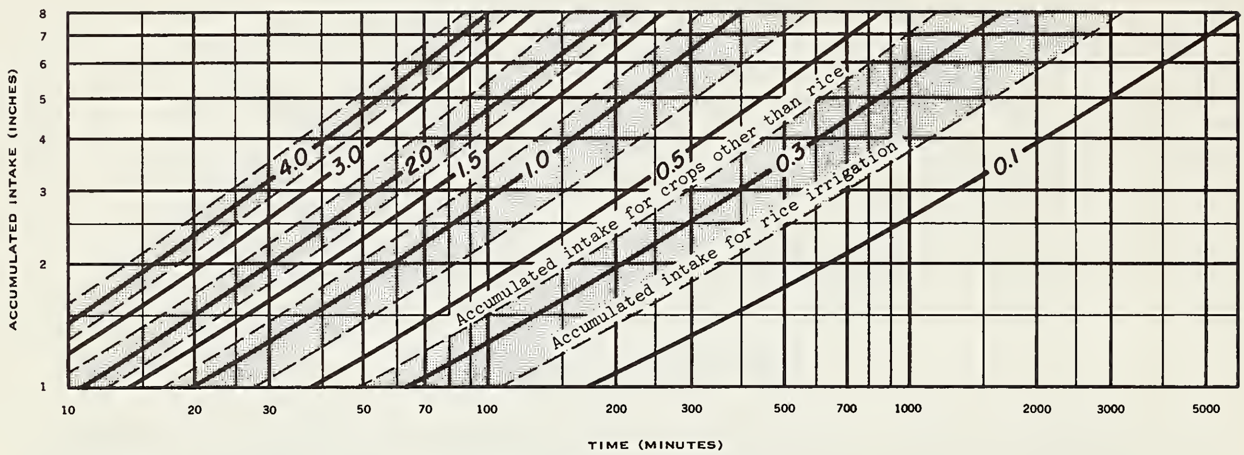

Figure 6-1.--Accumulated intake for irrigation by the contour-levee method.

Soil intake rates for the desired net depth of application should not exceed those upper limits shown in figure 6-1. For example, if a 3-inch application were planned for cotton, the intake opportunity time should not be less than 300 minutes. Intake rates for contour-levee irrigation are shown in local irrigation guides where they are known. Otherwise, they are measured by the cylinder-infiltrometer method.

Because of the difficulty of maintaining the flood on soils planted to rice, they should contain a restrictive layer with a permeability rate of 0.02 inch per hour or less.

Topography

For this method, best results are obtained where slopes do not exceed 0.5 percent. Greater slopes, however, can be reduced by land leveling. Where leveling is required, the soil must be deep enough to permit leveling without undue loss of productivity.

If contour levees are used for irrigating row crops, the slope in the direction of row drainage becomes a limiting factor. The maximum practical slope is that which will not result in erosion from storm runoff. In areas where this method is now being used, slope ranges from 0.05 to 0.3 percent depending on erodibility of the soil. The minimum slope is that which will provide adequate drainage, usually 0.05 to 0.15 percent. Slopes must be within these limits or must be obtainable at reasonable cost by landing leveling.

Climate

The contour-levee method can be used successfully for irrigating rice and close-growing crops in any climate to which these crops are adapted, provided the prerequisites regarding soil and topography can be met. Levees are usually temporary for row crops and are usually not built

until the crop needs to be irrigated for the first time so that they will not interfere with operation of the cultivating equipment. In humid areas where this method is common for irrigating row crops, rainfall usually is adequate during the early growing season and irrigation is not required until cultivation has been completed. When cultivation becomes necessary after an irrigation, the levees are plowed down by the cultivating equipment. They are then rebuilt to make maximum use of subsequent rainfall. In areas where insufficient rainfall during the early growing season would require frequent reconstruction of levees, the contour-levee method is not recommended for irrigating row crops.

Advantages

The contour-levee method has several advantages.

(1) It permits the irrigation of low-intake-rate soils that are difficult to irrigate by other methods.
(2) Maximum utilization of rainfall reduces seasonal irrigation requirements.
(3) Uniform distribution of water and high field-application efficiency are easily obtained.
(4) Since the same system removes excess storm runoff, adequate drainage can be provided at little extra expense. This is very important in areas of high rainfall.
(5) Installation costs depend largely on the amount of land preparation required. Where the unit volume of leveling is moderate, installation costs are low compared with most other methods.
(6) Simple, easily operated controls permit handling large irrigation streams with minimum labor. One irrigator can usually handle up to 300 acres including pump attendance.

Limitations in Use

Some limitations and disadvantages of the method are:

(1) It is restricted to irrigating crops that can stand temporary flooding for 12 hours or more without damage.
(2) It cannot be used successfully on soils having moderate to rapid intake characteristics (fig. 6-1).
(3) Some degree of land leveling is usually required.
(4) Large irrigation streams are required.
(5) Light net applications are difficult to make efficiently.
(6) Levees, ditches, and structures need frequent maintenance.

Land Preparation Requirements

Contour levees require some land preparation. Figures 6-2a, b, c, d illustrate the different degrees to which a typical 40-acre field can be prepared for this method of irrigation. Though these illustrations were prepared for irrigating rice, they are adaptable to the irrigation of field and forage crops.

Without land preparation, long levees, ditches, and canals may be required; water cannot be applied uniformly or efficiently; water management is difficult; and production costs, especially for labor, are high. Figure 6-2a shows the topography of a field before land preparation. It also shows the extent of levees and drains if levees were constructed at a vertical interval of 0.2 foot on the original topography.

Eliminating minor surface irregularities improves the topography of the field. Smoothing, usually with a land plane, permits laying out a usable irrigation and drainage system, but levees, ditches, and canals are still too long and basins are irregular in shape and variable in size, making efficient irrigation difficult (fig. 6-2b).

For more efficient operation of planting, cultivating, and harvesting equipment and for better water management, the levees should be parallel and the basins of uniform width (fig. 6-2c). The levees can be staked parallel on approximate contours first and each basin then leveled to a uniform plane, or the entire field can be leveled first and the levees then staked parallel and on the contour. This results in increased water-use efficiency, high crop yields, and reduced production costs.

An additional refinement that further increases water-use efficiency and facilitates water management consists of dividing the field into units or basins of equal size and shape by levees that are straight and parallel. The levees can be constructed first and the basins then leveled and each treated as a separate field, or the entire field can be leveled first and the levees constructed afterward. Where land is leveled by water leveling, level basins result. The slope required for drainage is obtained by plowing the basin toward the center, thus building up a ridge (fig. 6-2d).

Where conventional land leveling is used, the basins usually are sloping planes (p. 6-15). Neither type of basin is considered to have an advantage over the other.

These basins, equal in size and shape, while more expensive to construct, increase water-use efficiency and reduce labor costs.

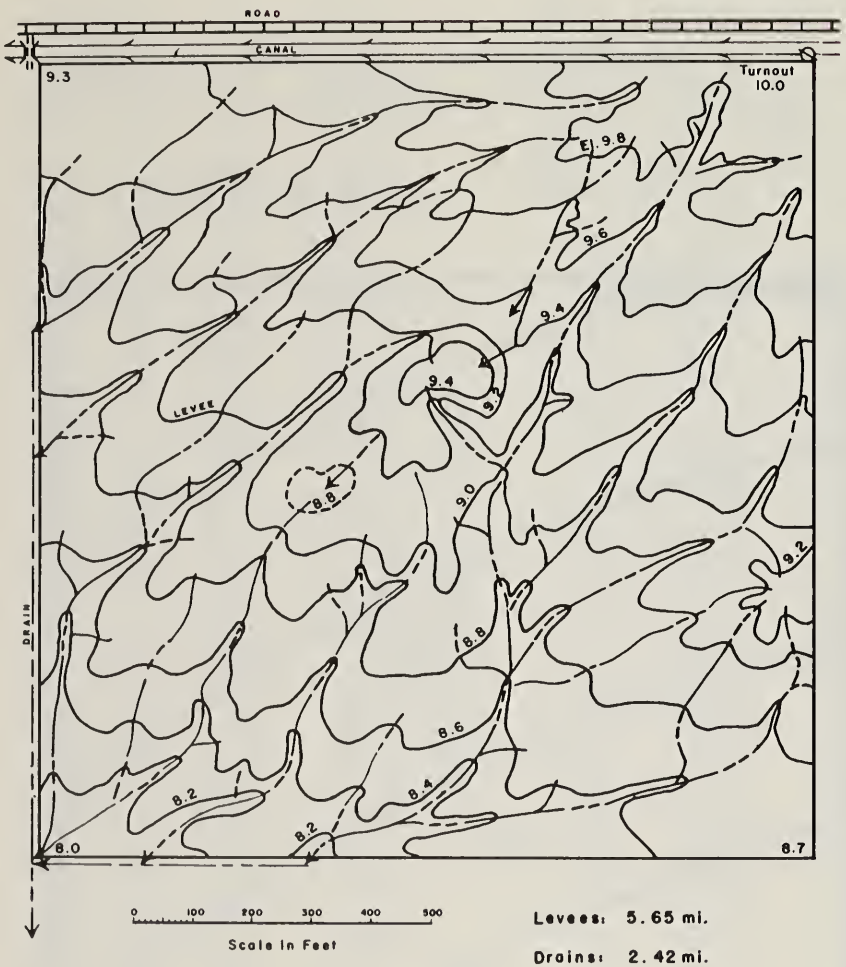

Figure 6-2a.--Typical topography of a 40-acre field to be irrigated by the contour-levee method showing levees and drains if land were not smoothed or leveled.

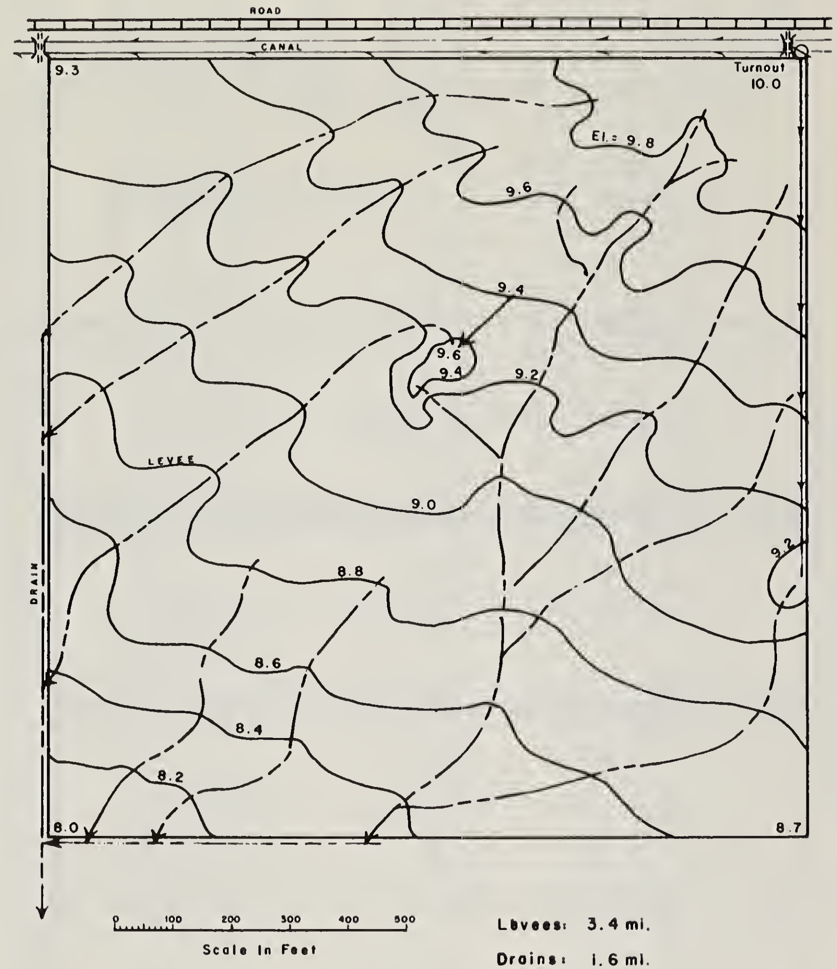

Figure 6-2b.--Same field showing contour levees after land smoothing.

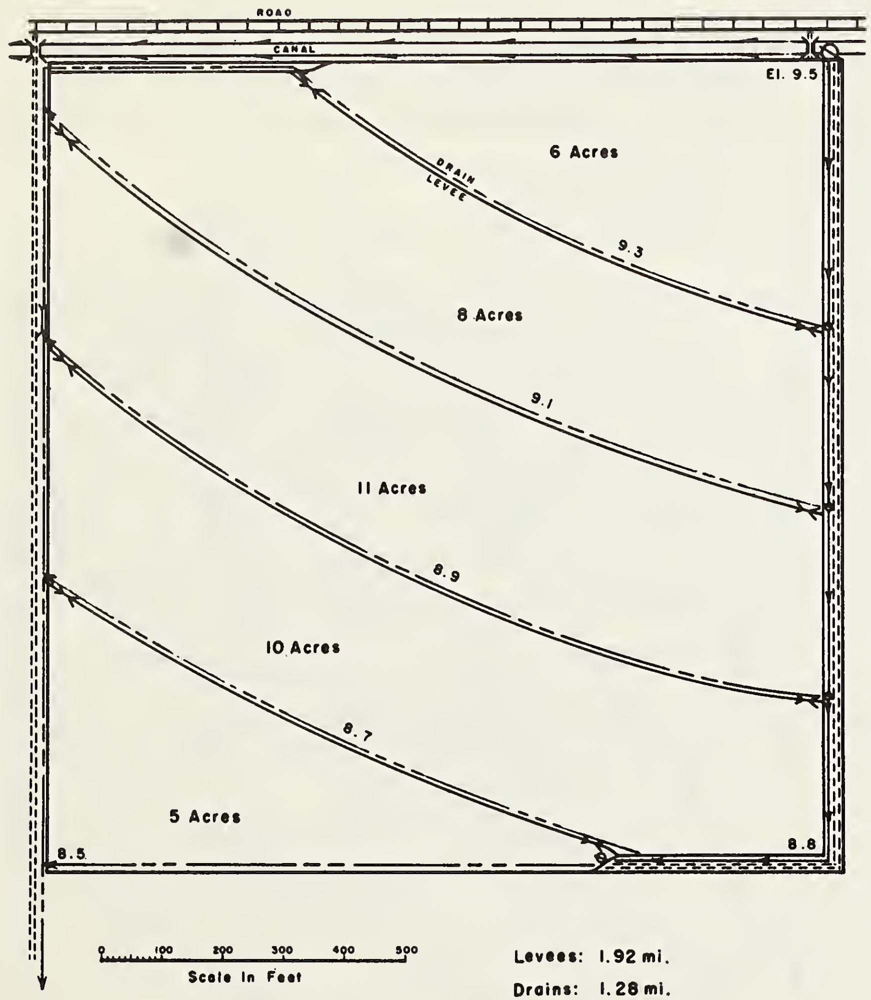

Figure 6-2c.--Same field after constructing parallel levees and leveling basins.

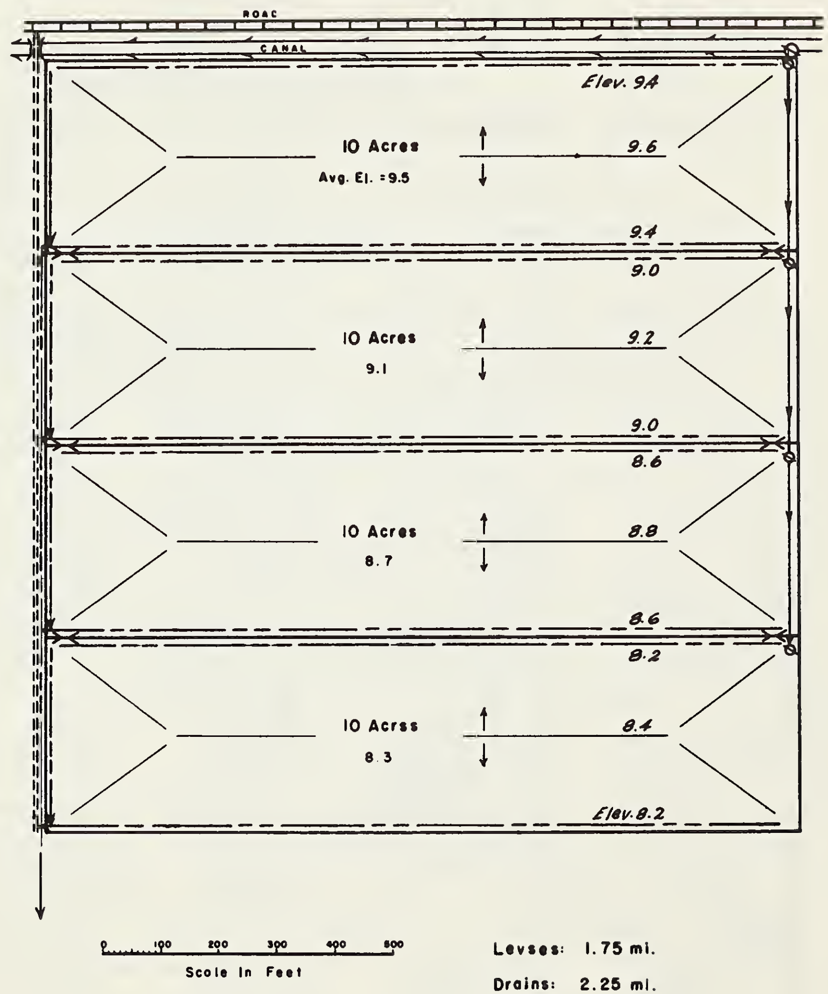

Figure 6-2d.--Same field after constructing uniform basins.

Detailed Investigations

Soils

A detailed soil map of the area to be irrigated is a prerequisite to planning a contour-levee system. The intake characteristics of each soil must be known. If they cannot be obtained from the local irrigation guide, they will have to be measured by the cylinder-infiltrometer method. For soils on which rice is to be irrigated, the permeability rate of the restricting layer must be known.

The available water holding capacity of the significant layers of each soil should be known. These are usually obtained from the local irrigation guide.

Topography

A topographic map of the area to be irrigated facilitates planning the contour-levee system. Information on the map should include, in addition to contour lines, the location and elevation of the water source and drainage outlet. The map should also show any pipelines, drains, powerlines, structures, roads, or other important physical features.

The topographic map can be based on either a conventional or grid survey. Aerial photographs may serve the purpose of a topographic map if old contour levees are visible and if they adequately describe the topography.

Water Supply

Dependable stream sizes available for irrigation should be measured or estimated. The available stream sizes determine the number of acres of a given crop that can be irrigated (p. 6-9).

The quality of the water with respect to its intended use should be determined.

Layout of Levee Systems

If an adequate contour map is available, the levee system can be laid out on the map before making the layout on the ground. This saves time and effort in the field.

The first step is to determine the maximum-size unit or basin that can be irrigated with the stream size available (sample calculations 3 and 4).

The shape of the basins is important. To prevent overtopping of the levees, the dimension of any basin in the direction of the prevailing wind should not exceed about 400 feet. Length of the basin may be restricted by drainage requirements. The channel above the levee along the lower

side of a basin removes both excess irrigation water and storm runoff. Thus this length should be limited to that which permits the channel to provide such removal in a reasonable length of time. Basins draining in one direction should not be longer than 660 feet. Where the basin has more than one drainage outlet, its length may be increased.

The levees must be laid out on the contour or so located that they will be on the contour after land preparation. If practicable they should be laid out parallel to each other. To facilitate planting, tillage, and harvesting levees should be straight or gently curving.

The ideal vertical interval between levees is about 0.2 to 0.4 foot. Smaller vertical intervals can be used on very flat land to reduce the size of the unit areas to that compatible with the available irrigation stream. Somewhat larger vertical intervals may be used in small parts of a field to maintain a minimum horizontal interval of about 40 feet. Larger vertical intervals, however, require higher levees, usually resulting in a decrease in water-use efficiency.

The levees should provide basins of nearly equal size. This makes irrigation easier and increases water-use efficiency. After the contour levees are located, the basins are closed by constructing end levees. A typical layout of a contour-levee system is shown on page 6-15.

Locate roadways to provide access to each basin by farm machinery (p. 6-15). These roadways are of particular importance if harvesting has to be done in wet weather. Culverts or bridges must be provided at each ditch crossing.

Levee Dimensions

The settled height of the levees must equal the sum of the vertical interval between levees, the depth of water to be applied, and a freeboard of at least 3 inches (0.25 foot) for protection against wave action. For noncompacted levees at least 0.3 foot more should be added for settlement. The constructed height of a typical levee is computed as follows:

Vertical interval between levees	0.2 foot
Depth of water to be applied (3.6 in.).............	.3 foot
Freeboard..	.3 foot
Settlement allowance...............................	.3 foot
Constructed height.................................	1.1 feet

Where levees are torn down and rebuilt to facilitate planting and tillage of row crops, side slopes should be no steeper than 1-1/2 horizontal to 1 vertical. Where they are permanent as in pastures, side slopes should be no steeper than 3 or 4 to 1 to facilitate the use of mowing machinery and to minimize damage by the trampling of livestock.

A drainage channel no less than 0.5 foot deep with side slopes no steeper than 1-1/2 horizontal to 1 vertical is provided along the upper side of each levee. The material removed from the drainage channel is used to build the levee (p. 6-15). Temporary levees are usually built with border plows or border disks and wider, more permanent levees with blade graders.

Irrigation Stream Sizes

The minimum-size irrigation stream for all adapted crops other than rice must equal or exceed the greater of the following: (1) A stream large enough to satisfy peak water use requirements of the crop and to overcome deep percolation and other losses. (2) A stream large enough to permit coverage of the average-size leveed basin in a maximum of one-fourth the time required for the soil to absorb the net amount of water to be applied.

The minimum required stream that satisfies the first criterion is computed by the formula:

$$Q = \frac{A \times F_g}{f \times h} \quad \text{See nomenclature.}$$

To compute the minimum-size stream that satisfies the second criterion, intake characteristics of the soil (fig. 6-3), average size of the basins, and vertical interval between levees must be known.

The procedure for computing the minimum stream size is illustrated in the sample calculation which follows.

Sample calculation 1.--Determining minimum stream size for crops other than rice

Given:

An 80-acre field of cotton containing 16 basins of nearly equal size (A)........................	$A = 80$ acres
Net depth of application (from irrigation guide).	$F_n = 2.5$ in.
Gross depth of application at an estimated 70 percent efficiency..............................	$F_g = 3.6$ in.
Time allowed for one complete irrigation as agreed on with the irrigator (no greater than F_n/daily peak use rate)........................	$f = 8$ days
Daily system operation time as agreed on with the irrigator..	$h = 12$ hr
Soil intake characteristics (from cylinder-infiltration measurements)....................	See figure 6-3
Average area of 16 basins in 80-acre field.......	5 acres
Vertical interval between levees................	$vi = 2.4$ in.

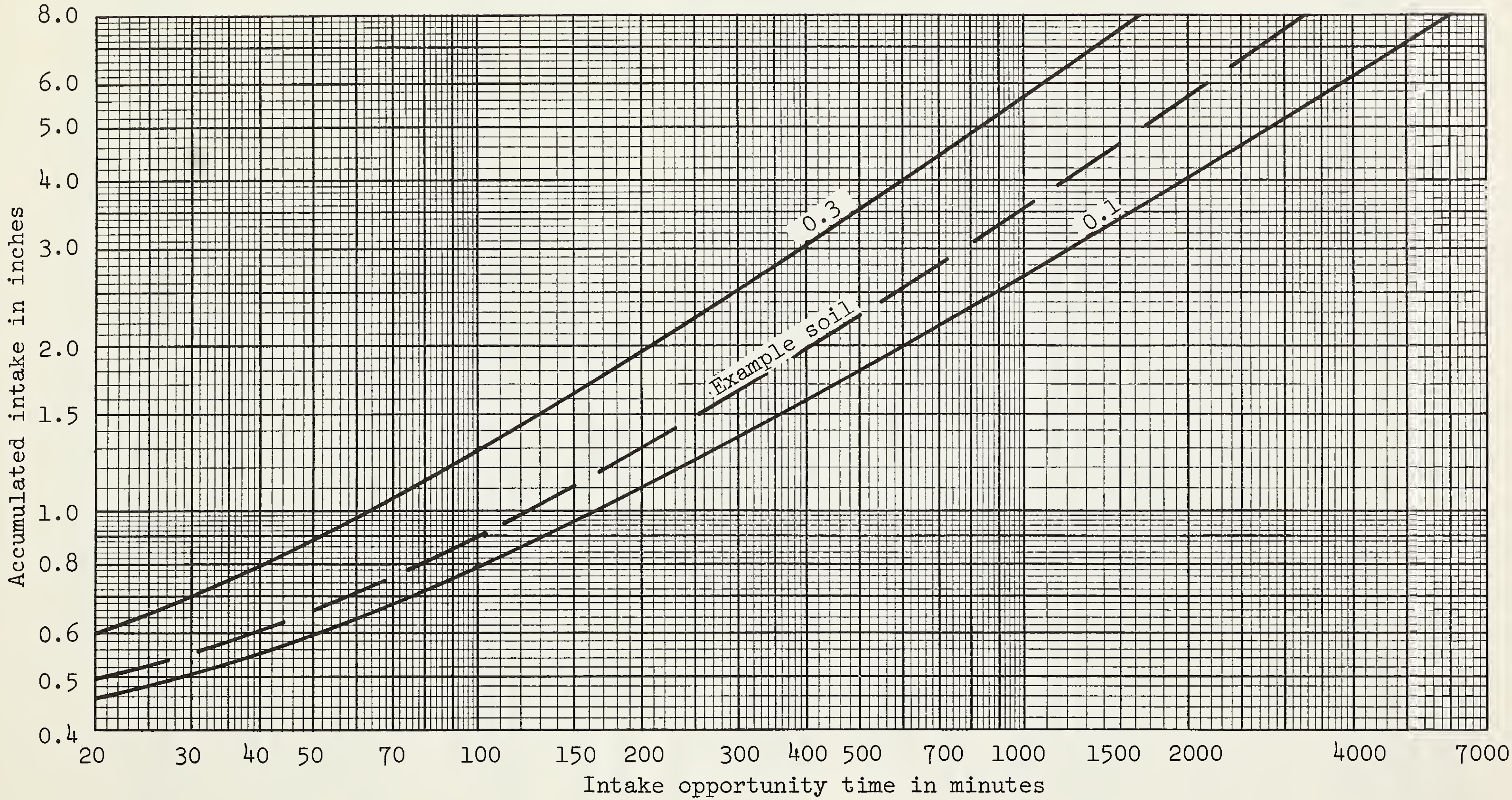

Figure 6-3.--Accumulated intake vs. time for example soil.

<u>Find</u>:

The minimum stream size (Q) that satisfies the two criteria.

<u>Procedure</u>:

Compute the minimum stream size required to satisfy the first criterion as follows:

$$Q = \frac{A \times F_g}{f \times h} = \frac{80 \text{ acre} \times 3.6 \text{ in.}}{8 \text{ days} \times 12 \text{ hr/day}} = 3.0 \text{ acre-in. per hr} = \underline{\underline{3.0}} \text{ cfs}$$

Using the example soil curve shown in figure 6-3, find the time (T_n) required for the net depth of application (F_n = 2.5 inches) to infiltrate the soil. T_n is 580 minutes.

Allowing one-fourth of the time (T_n), or 145 minutes, to cover an average-size basin, find the average depth of water that infiltrates the soil during this period. Water infiltrates the soil only along the lower side of the basin during $T_{n/4}$; there is no infiltration along the upper side. The basin is covered for 145 minutes along the lower side and for zero minutes along the upper side with an average coverage time of 72-1/2 minutes. Using figure 6-3, find the depth of water that infiltrates the soil in 72-1/2 minutes. This is 0.76 inch.

To this average depth of infiltration add the average depth of water over the basin at the end of this period. Since the vertical interval between levees is 2.4 inches, the water is that deep along the lower side of the basin and has no depth along the upper side. Thus the average depth is one-half of the vertical interval (vi) or 1.2 inches.

Compute the minimum stream size required to satisfy the second criterion as follows:

Required stream size per acre (q):

$$q = \frac{(0.76 \text{ in.} + 1.2 \text{ in.}) \times 60}{145 \text{ min}} = 0.811 \text{ acre-in. per hr} = 0.811 \text{ cfs per acre}$$

Required total stream size (Q):

$$Q = 5 \text{ acres} \times 0.811 \text{ cfs per acre} = \underline{\underline{4.06}} \text{ cfs}$$

Since the second criterion requires a greater stream size, the value 4.06 cubic feet per second is used.

In rice irrigation, there are three critical operations, any one of which may determine the required irrigation stream size: (1) Flushing, which usually follows seedbed preparation and dry planting. The irrigation stream must be large enough to cover a basin in one-fourth the time required for the soil to absorb the net amount of water applied. (2) Flooding, which is started when the plants are about 8 to 10 weeks old and are

using water at a maximum rate. The irrigation stream must be large enough to flood the entire design area to a predetermined depth--usually 3 to 4 inches--in the time required for depletion, at the peak rate, of one-half the available moisture in the root zone of the soil. (3) Maintaining the flood until about 2 weeks before harvest. The irrigation stream must be large enough to satisfy peak-period consumptive use and overcome deep percolation losses.

The procedure used for determining minimum required stream size for each of these critical operations is illustrated in the sample calculation which follows:

Sample calculation 2.--Determining minimum stream size for rice irrigation

Given:

An 80-acre field of rice containing 16 basins of nearly equal size (A)........................	A = 80 acres
Available water holding capacity of soil at root zone depth (18 in.)........................	= 3.6 in.
Saturated moisture capacity of soil at root zone depth..	= 7.35 in.
Permeability of restricting layer................	= 0.002 in/hr
Net depth of application (from irrigation guide).	F_n = 1.8 in.
Soil intake characteristics (from cylinder-infiltrometer measurements)....................	See figure 6-3
Peak-period consumptive-use rate................	u = 0.3 in/day
Vertical interval between levees................	vi = 2.4 in.

Find:

The minimum stream size (Q) required for flushing, flooding, and maintaining the flood.

Procedure:

For flushing.--Using figure 6-3, find the time (T_n) required for the net depth of application (F_n = 1.8 inches) to infiltrate the soil. T_n is 345 minutes.

Allowing one-fourth of T_n, or 86 minutes, to cover an average-size basin (5 acres), find the average depth of water that infiltrates the soil during this period. This depth is 0.62 inch (fig. 6-3).

To this average depth of infiltration, add the average depth of water over the surface of the basin at the end of this time period. This average depth is equal to one-half the vertical distance between the levees or one-half of 2.4 inches = 1.2 inches.

Required stream size per acre (q):

$$q = \frac{(0.62 \text{ in.} + 1.20 \text{ in.})\ 60}{86 \text{ min}} = 1.27 \text{ acre-in. per hr}$$
$$= 1.27 \text{ cfs per acre}$$

Required total stream size (Q):

$$Q = 5 \text{ acres} \times 1.27 \text{ cfs per acre} = \underline{\underline{6.35}} \text{ cfs}$$

For flooding.--Find the time required for depletion of one-half the available soil moisture:

$$\frac{1/2 \times 3.6 \text{ in.}}{0.30 \text{ in. per day}} = 6 \text{ days} = 144 \text{ hr}$$

Find the depth of application to produce a 3-inch flood over the design area:

Depth of application required to saturate the soil.....	7.35 in
One-half the vertical interval between levees..........	1.20 in
Depth percolation losses (144 hr x 0.002 in. per hr)....	0.29 in.
Depth of flood...	3.00 in.
Total application..................................	11.84 in.

Then find the minimum required irrigation stream:

$$Q = \frac{80 \text{ acres} \times 11.84 \text{ in.}}{144 \text{ hr}} = 6.58 \text{ acre-in. per hr}$$
$$= \underline{\underline{6.58}} \text{ cfs}$$

For maintaining the flood.--Find the minimum stream size that maintains the flood by satisfying peak consumptive use and replacing the amount lost by deep percolation:

$$Q = 80 \text{ acres} \left(\frac{0.30 \text{ in. per day}}{24 \text{ hr}} + .002 \text{ in. per hr}\right)$$
$$= 1.16 \text{ acre-in. per hr}$$
$$= \underline{\underline{1.16}} \text{ cfs}$$

Thus the required minimum irrigation stream is the 6.58 cubic feet per second required for the flooding operation.

Delivery Systems

The delivery system consists of the facilities required to convey water from the source of supply to the highest point in each field to be irrigated. The water may be conveyed above ground level in elevated field ditches or in low-pressure pipelines. These facilities also include the structures, valves, and measuring devices required to control and direct the water to the individual fields as needed and at the designed rate of flow.

Pipelines have obvious advantages over open ditches; they are buried, take no land out of cultivation, and require a minimum of maintenance. Open ditches cost less to install, but weed control and sediment removal are expensive.

The capacity of the delivery system must be equal to or greater than the sum of the minimum required irrigation stream for each field (sample calculations 1 and 2).

In the sample plan no delivery system is shown since the source of supply, a well, is located at the highest point in the field (fig. 6-4). The irrigation supply ditch along the north boundary of the field is considered a part of the application system.

Application Systems

The application system consists of the facilities required to distribute and apply water on all parts of a field. These facilities may include open ditches, pipelines, levees, turnouts, control structures, culverts, and other devices.

An irrigation head ditch or pipeline is used to convey water to the highest basin in each series. Water is turned into these upper basins through turnouts in head ditches or through valves in pipelines (fig. 6-5).

The head ditch consists of two parallel levees or dikes. The construction material may be borrowed from land-grading operations, from nearby borrow areas, or from the center area between the levees themselves. If levee material can be borrowed elsewhere economically and conveniently, center borrow ditches should not be used. Center borrow ditches must usually be larger than required for adequate capacity to obtain enough material for construction of the levees. Ditches of this type are necessarily wide and take up space that otherwise might be cultivated.

Since the system operates by gravity, water is conveyed above ground surface and a head of not less than 0.5 foot must be provided at the turnouts. The top of the levees forming the head ditch must be at least 1.5 feet above the highest part of the irrigated area. The head ditch should have stable side slopes, usually 1-1/2 horizontal to 1 vertical.

Several types of turnouts are used to introduce water into the basins. One of the most popular consists of a pipe with a gate on the upstream end. A 10-foot section of corrugated metal pipe with an inexpensive light steel gate is easy to install and has proven very satisfactory. Pipe diameter is determined by the design rate of flow and the head provided to obtain that flow. Several types of turnout that have proven satisfactory are shown in chapter 3.

Inside the irrigated area, water is usually conveyed from the head ditch or pipeline to the lower basins by V-type irrigation ditches which also serve as drainageways. The capacity of these ditches must be equal to the minimum required irrigation stream <u>or</u> to the computed drainage requirements, whichever is the greater. They should be at least 0.5 foot deeper than the V-type drains along the upper sides of the contour levees or a minimum of 1 foot.

There should be roadways between each series of basins for easy access to all parts of the field. Waste material placed between two parallel

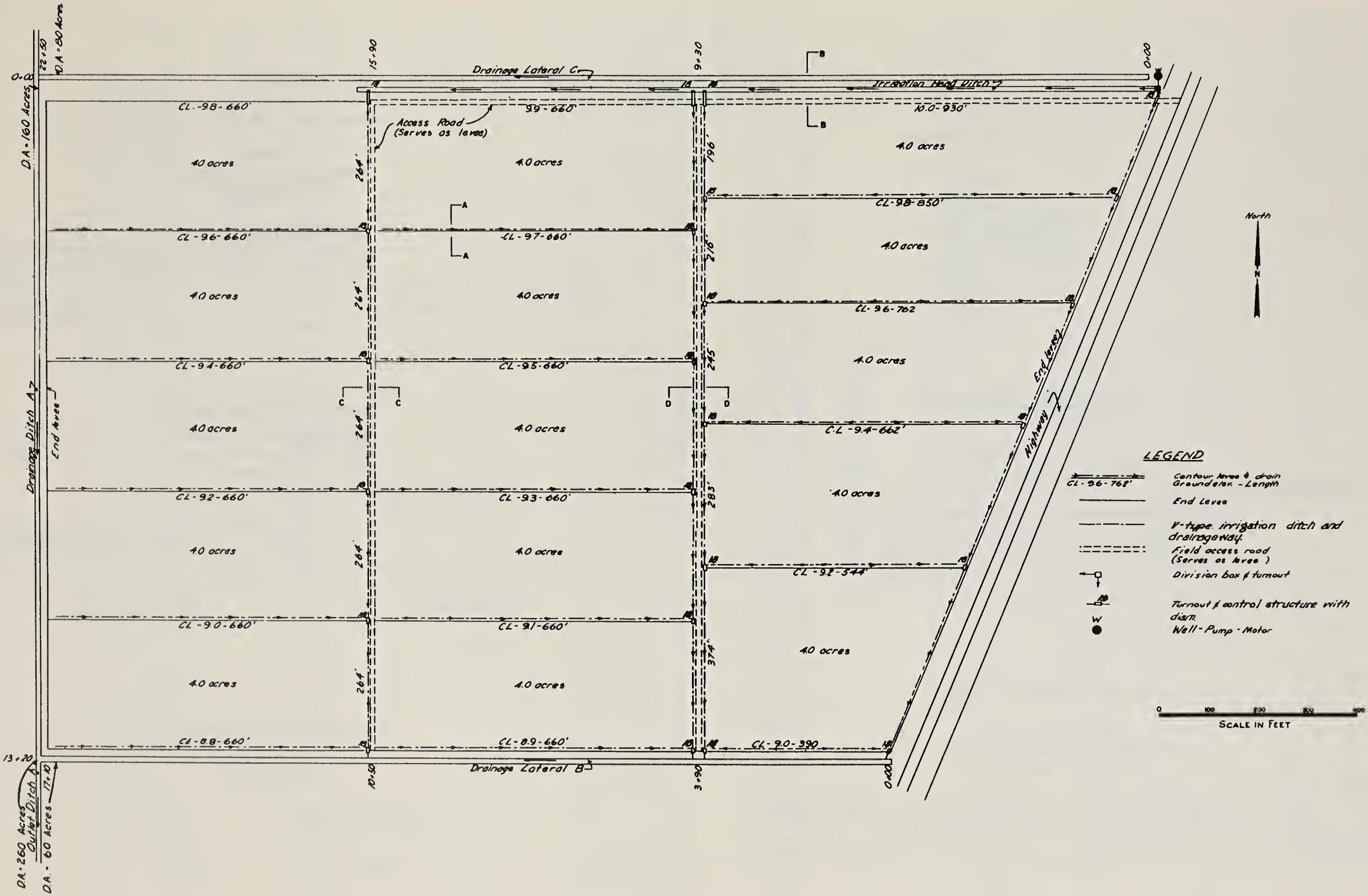

Figure 6-4.--Engineering plan for sample contour-levee irrigation system.

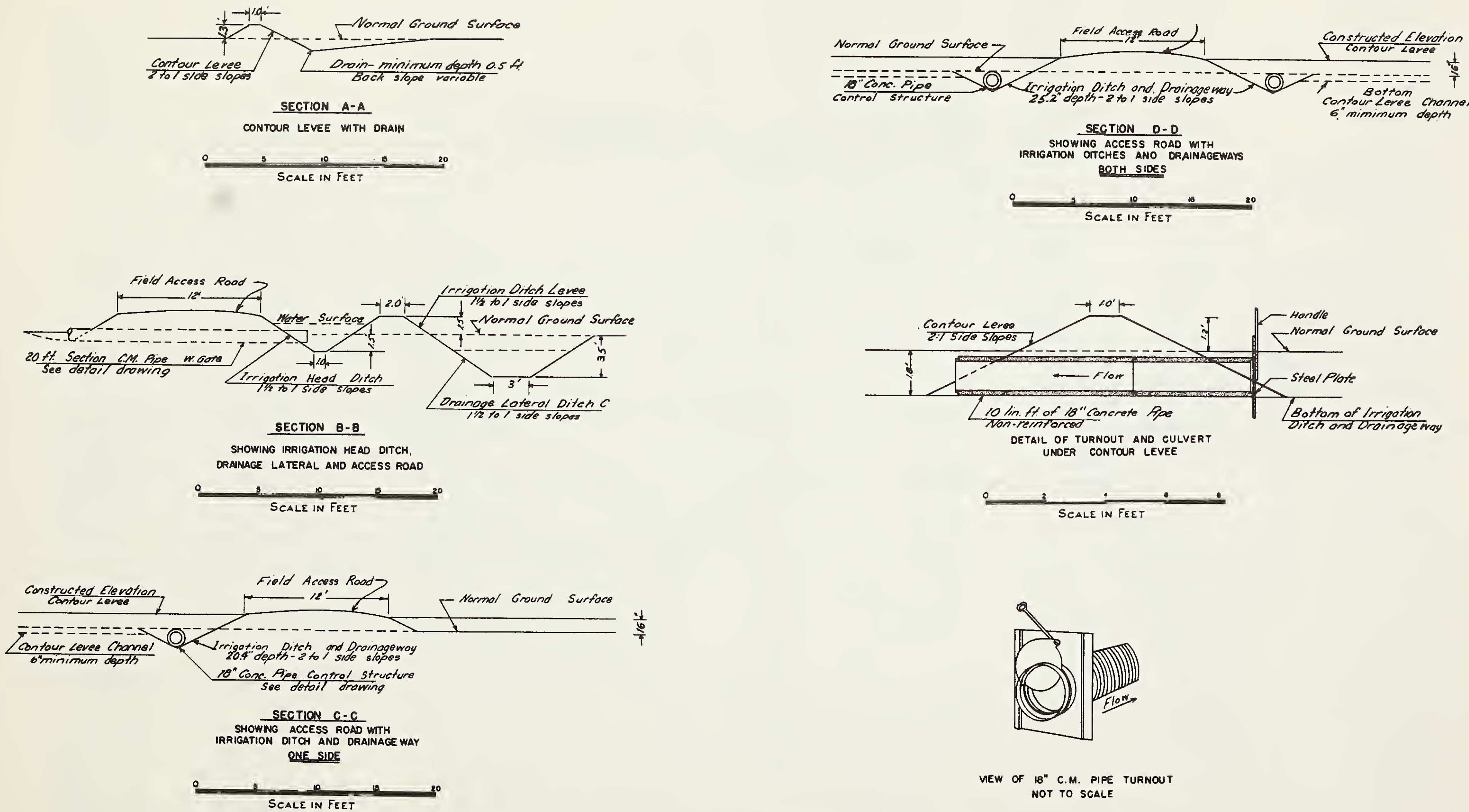

Figure 6-5.--Cross sections--sample contour-levee irrigation system.

V-type irrigation ditches can be used to form the roadway. The roadway also acts as an end levee and must be equal in height to the contour levees. Slopes should be no steeper than 1-1/2 horizontal to 1 vertical except that in pastures they should be no steeper than 3 or 4 to 1. (See section D-D, figure 6-5.)

To retain, control, and eventually remove the irrigation water suitable control structures must be placed in the irrigation ditches under each contour levee. Several types of structures have been developed. One is a concrete pipe culvert with an adjustable steel plate at its upper end (fig. 6-5). Another is a sheet metal structure that has flashboards for water control. In some levees fixed-crest weirs made of sheet metal or other suitable material are added as a further control.

The capacity of any control structure should be equal to that of the ditch in which it is placed. The structure should be designed to operate under a head not exceeding 0.5 foot. If a pipe is used, the normal diameter should be no less than 10 inches.

Drainage Requirements

The irrigation application system provides adequate drainage within the design area. Providing an adequate outlet and preventing runoff from adjacent areas entering the irrigated area are the other drainage problems.

The outlet is usually a trapezoidal channel able to provide adequate drainage for both the irrigated area and any other area it may serve. The outlet or a channel lateral to it serves the lowest basin in each series. Additional channels must be provided around the boundaries of the drainage area where needed to prevent the entrance of runoff from higher areas (fig. 6-4).

In computing the capacity of the outlet channel and its laterals provide adequate drainage for the least water-tolerant crop grown in the rotation.

Operation

The method of operation varies with the crop being irrigated and with the owner's preference for operating time. The usual methods follow.

Crops Other Than Rice

Individual basins in a series are irrigated consecutively, beginning with the highest and ending with the lowest. All control structures in the irrigation ditch serving a series of basins are closed and water from the head ditch or pipeline is then turned into the highest basin in the series. The irrigation stream discharges into the first basin

until the gross application depth plus the depth needed to cover the basin has been applied. Then the structure controlling this basin is partially opened, allowing the irrigation stream to flow into the second or next lower basin. The water flows into the second basin until the gross application has been applied. Then the third basin is flooded in similar manner. This process is continued downstream until the gross application for the series has been applied.

After water has remained on the highest basin until the desired depth has infiltrated the soil, the control structure in this basin is completely opened and the water drains off and flows onto the next lower basin. This process is continued until a complete series of basins is irrigated. This operation may be undertaken during daylight only (sample calculation 3) or may be a continuous one. Continuous operation is the more efficient since only the excess water from the last or lowest basin in a series need be drained off as waste.

Other series of basins in the field are then irrigated in like manner. When the field is not being irrigated, all control structures in the irrigation ditches are left open for drainage.

Operation for Rice

In rice irrigation, there are four operations: moisture control for germination, flooding, maintaining the flood, and removing the flood.

Moisture control for germination.--Rice is seeded either by drilling dry or by broadcasting into water from an airplane. When drilling is followed by a period of dry weather, flushing is needed to germinate the seed or to prevent loss of young seedlings through lack of moisture. The flushing process for rice is the same as for other crops.

When seeding is done from the air, the basins are flooded to a shallow depth before seeding. As soon as the rice sprouts, the water is drained off to hasten growth of the rice plants and permit them to develop deep root systems.

Flooding.--Each basin is flooded with water so as to provide weed control without damage to the rice plants. Rice is normally flooded twice during the growing season. About 3 to 4 weeks after seeding the basins are flooded to a shallow depth to control weeds and to provide adequate moisture. This flood is held on the basins for about 2 weeks after which it may be drained off and the soil surface allowed to dry out. Drying helps control root maggots, algae, and fungi. It also provides a favorable period for applying fertilizer and permits the rice straw to stiffen and resist lodging.

The second flooding comes about 7 to 9 weeks after seeding. Water requirements are high because this is during the peak consumptive-use period. Each basin is flooded to a depth of 3 inches or more and the flood is maintained for 9 to 10 weeks or from 2 to 3 weeks before harvest.

Each series of basins is flooded separately, one series being completely flooded before another is started. When the design depth of flood has been reached on the first basin, the water is turned into the next lower basin and the process repeated downstream until all basins in a series are flooded. The design depth of flood is maintained in each basin by using sheet metal weir structures in the levees or by manipulating the turnouts or control structures in the irrigation ditch.

When one series of basins has been completely flooded, the other series are then flooded in like manner.

Maintaining the flood.--The design depth of flood is maintained on all basins simultaneously by adding water at the rate needed to overcome losses due to evaporation, transpiration, deep percolation, and seepage through the levees.

Removing the flood.--Near the end of the flood maintenance period the water is cut off and the flood allowed to infiltrate the soil profile so that only a minimum remains to be drained off as waste. All water should be removed from the field about 2 weeks before the rice harvest to provide a dry surface for harvesting machinery.

Water Use Efficiency

As in other surface methods of irrigation, the efficiency of water use obtained with the contour-levee method depends on the physical characteristics of the soil, adequacy of land preparation, planning and construction of the system, and care exercised in its operation. Assuming good planning, construction, and operation, 65 to 70 percent efficiency may be obtained in irrigating crops other than rice. Different degrees of efficiency are obtainable for the three separate operations used in irrigating rice. When these are averaged, the overall efficiency is 70 to 80 percent.

Sample Design Problems

The design procedure for contour-levee irrigation systems is presented here by sample calculations. Those selected consist of designing combined contour-levee irrigation and drainage systems--one for cotton and one for rice--for a 60-acre field in the delta area of Louisiana (fig. 6-4). The surface of the field has been improved by land leveling. The design procedure for irrigating cotton is presented in sample calculation 3 and for rice in sample calculation 4.

Sample calculation 3.--Designing contour-levee irrigation and drainage system for cotton irrigation

Given:

A 60-acre field of cotton (A)..................	A = 60 acres
Available stream size = 1,500 gpm............	Q = 3.33 cfs
Net depth of application......................	F_n = 2.5 in.
Maximum time allowed for one irrigation.......	f = 8 days
Hours of operation (daylight only)...........	h = 12 to 14 hr
Soil intake characteristics...................	See figure 6-3
Vertical interval between levees, 0.2 ft......	vi = 2.4 in.

Find:

Minimum required stream per acre, q
Maximum size of basin
Required number of basins
Time required for one irrigation
Application efficiency
Irrigation ditch sizes
Drainage requirements
Turnout and culvert sizes

Procedure:

In figure 6-3 find the time (T_n) required for the net depth of application (F_n = 2.5 in.) to infiltrate the soil. T_n is 580 minutes.

Using figure 6-3 and allowing one-fourth T_n, or 145 minutes, to cover one unit or basin, find the average depth of water that infiltrates the soil during this period. Average time = $\frac{145}{2}$ = 72.5 minutes. This depth is 0.76 inch.

Average depth of water in surface storage at the end of time period

$$\frac{Tn}{4} \text{ is } 1/2 \text{ vi or } \left(\frac{2.4}{2}\right) \text{ or } 1.2 \text{ inches}$$

Minimum required stream size per acre (q):

$$q = \frac{(0.76 \text{ in.} + 1.2 \text{ in.})\ 60}{145 \text{ min}} = 0.811 \text{ acre-in. per hr}$$
$$(0.811 \text{ cfs per acre})$$

Maximum size of basin or unit area:

$$\frac{\text{Available stream size}}{\text{Minimum stream size per acre}} = \frac{3.33 \text{ cfs}}{0.811 \text{ cfs per acre}}$$
$$= 4.11 \text{ acres}$$

Required number of basins: $= \frac{60 \text{ acres}}{4.11 \text{ acres}} = 14.6$

Thus the 60-acre field is divided into 15 basins of 4 acres each, each requiring a minimum stream size of

4 acres x 0.811 acre-in. per hr or 3.24 acre-in. per hr (3.24 cfs)

The available stream size of 3.33 cubic feet per second exceeds the minimum and will be used.

Time required for one irrigation

The average intake-opportunity time for one basin is equal to the average of the time at the lower edge (580 min + 145 min = 725 min) and at the upper edge (580 min), or 652 minutes.

In figure 6-3 find the average depth of application at time equal to 652 minutes. This is 2.7 inches. Check to see if the inflow stream (Q = 3.33 cfs) will irrigate the entire area within the allowable time, f = 8 days.

Determine the number of basins which can be irrigated per day within the allowable time of 12 to 14 hours with the stream (Q = 3.33 cfs).

Total volume of water required per basin for the average depth of application = 4 acres x 2.7 inches = 10.8 acre-inches.

The volume of water required for surface storage in one basin is 4 acres x 1.2 inches or 4.8 acre-inches. Depending on the irrigation sequence and arrangement of basins and ditches, some of the surface storage may be reused on lower basins. It is assumed here that the surface storage from two-thirds of the basins (10 in this example) may be drained off and used on lower basins. It is assumed also that 100 percent of the volume of water drained from the 10 basins is available for filling lower basins.

To fill three typical 4-acre basins only one requires filling the storage volume (4.8 acre-inches) from the "fresh" supply. Calculate time required to fill a series of basins as follows:

One basin $\frac{10.8 \text{ acre-in.} + 4.8 \text{ acre-in.}}{3.33 \text{ acre-in. per hr}} = 4.7 \text{ hr}$

Two basins $\frac{2(10.8 \text{ acre-in.}) + 4.8 \text{ acre-in.}}{3.33 \text{ acre-in. per hr}} = 7.9 \text{ hr}$

Three basins $\frac{3(10.8 \text{ acre-in.}) + 4.8 \text{ acre-in.}}{3.33 \text{ acre-in. per hr}} = 11.2 \text{ hr}$

The actual time to complete an irrigation of three basins depends on management of the drained water. The first basin can be drained of surface storage after 12.1 hours and the second 16.8 hours after water starts to fill the first basin.

Thus three basins could be irrigated within the allowable time, 12 to 14 hours.

In figure 6-4, each of the three segments of the field contains five basins.

Each series can be irrigated in 2 days--two basins in 1 day and three the next. The 15 basins (60 acres) can be irrigated in 6 days, which is within the allowable time, f = 8 days.

Determine field application efficiency in percent (E).

$$E = \frac{\text{Volume needed to refill soil x 100}}{\text{Volume actually applied}}$$

The volume needed to refill the soil in one basin is 4 acres x 2.5 inches, or 10 acre-inches.

Efficiency when two basins (8 acres) are irrigated:

$$E = \frac{(2 \times 10 \text{ acre-in.}) \times 100}{(2 \times 10.8 \text{ acre-in.}) + 4.8 \text{ acre-in.}}$$

$$= \frac{20 \times 100}{26.4} = 76 \text{ percent}$$

Efficiency when three basins (12 acres) are irrigated:

$$E = \frac{(3 \times 10 \text{ acre-in.}) \times 100}{(3 \times 10.8 \text{ acre-in.}) + 4.8 \text{ acre-in.}}$$

$$= \frac{30 \times 100}{37.2} = 81 \text{ percent}$$

Average application efficiency for the 60-acre field:

$$\frac{3 \times 8 \text{ acres}}{60 \text{ acres}} (76 \text{ percent}) + \frac{3 \times 12 \text{ acres}}{60 \text{ acres}} (81 \text{ percent})$$

Average E = 0.4 (76 percent) + 0.6 (81 percent) = 79 percent

Since the time required to apply the needed depth of water is within the time allowable and the field application efficiency is within acceptable limits, the irrigation phase of the design is satisfactory.

Irrigation ditch design

The required capacity of the irrigation field ditch shown in section B-B, figure 6-5, is equal to the available stream size or 3.33 cubic feet per second. A ditch with a bottom width of 1 foot, a depth of 2.2 feet, side slopes of 1-1/2 to 1, on a hydraulic gradient of 0.000125 foot per foot and an "n" value of 0.045 will have a capacity of 3.59 cubic feet per second, thus meeting this requirement.

Drainage requirements

The required capacities of the drainage ditches shown in figure 6-4 are computed using the applicable drainage coefficient curve (fig. 6-6). The required capacities are:

Ditch	Reach	Drainage area[1]	Required
		Acres	*Cubic feet per second*
Outlet A	Below 13+20	260	19.0
Drainage A	0+00 to 13+20	160	12.5
Lateral B	0+00 to 17+10	60	5.6
Lateral C	0+00 to 22+50	80	7.0
Interior drain-ageways	All	20	[2] 2.3 3.33

[1] See drainage areas on figure 6-4.

[2] Since the irrigation stream (3.33 cfs) is larger than the required drainage capacity (2.3 cfs), 3.33 cfs is used for design purposes.

By using Corps of Engineers hydraulic tables, we find that a minimum-size ditch with the following dimensions carries 20 cubic feet per second with a hydraulic gradient of 0.0005 foot per foot and an "n" value of 0.04.

Bottom width, 3 feet; depth, 3 feet; side slopes, 1 to 1

This minimum-size ditch will thus meet the capacity requirements for the outlet ditch A and laterals B and C (fig. 6-4).

Turnout and culvert design

The required capacity of turnouts and culverts must be equal to the irrigation stream of 3.33 cubic feet per second. Sizes are determined by the formula, $Q = Ca\sqrt{2gh}$.

C = Coefficient of discharge

a = Area of opening square feet

g = Acceleration of gravity, feet per second

h = Available head in feet

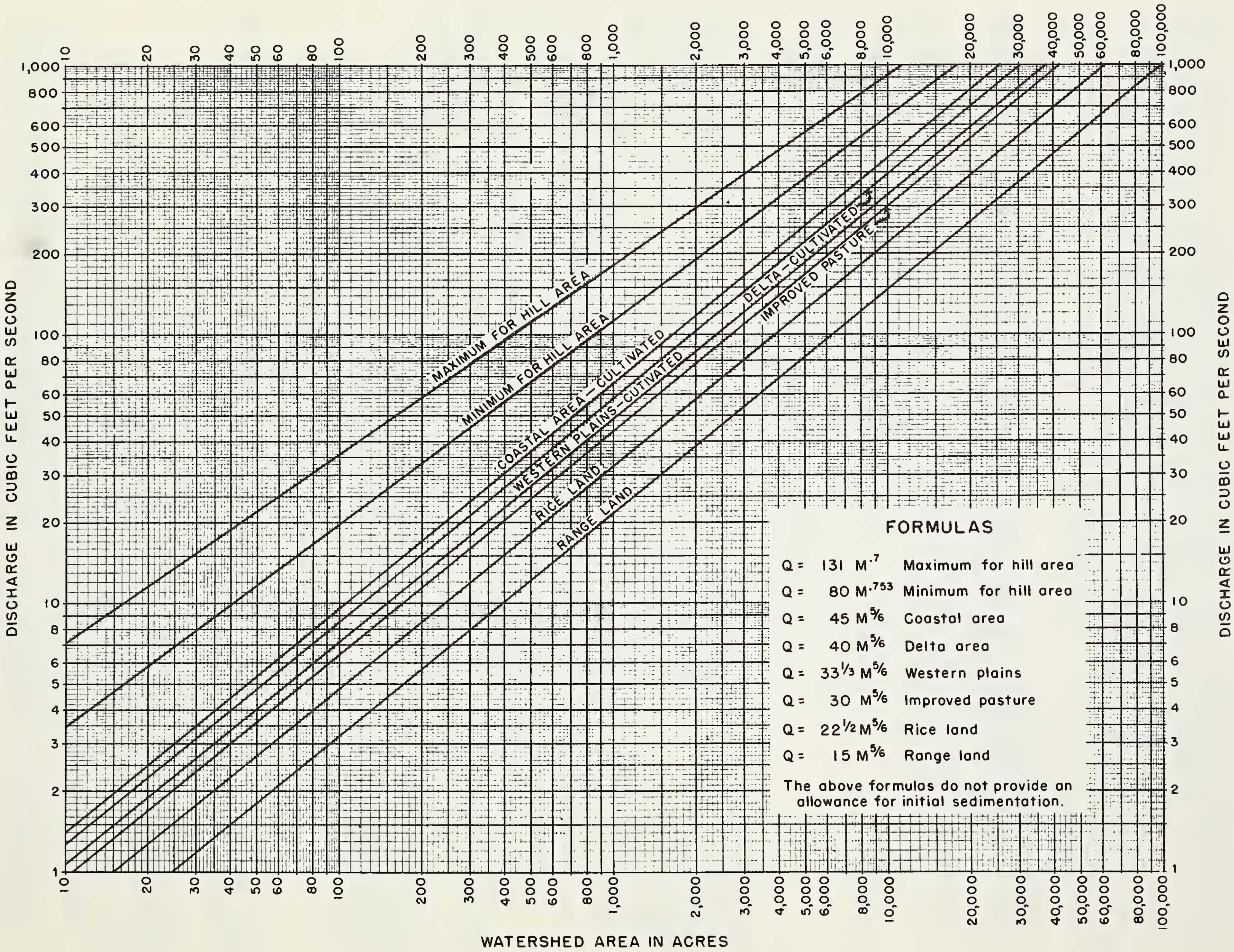

Figure 6-6.--Drainage-coefficient curves for Southwest.

Try using an 18-inch concrete pipe, 10 feet long, with a square-cornered entrance operating under a head of 0.1 foot. The computation becomes:

$$Q = 0.81 \times 1.767 \sqrt{2 \times 32.2 \times 0.1}$$
$$= 3.63 \text{ cubic feet per second (satisfactory)}$$

Interior irrigation ditches and drainageways
The required capacity of the combined irrigation ditches and drainageways shown in sections C-C and D-D of figure 6-5 must be equal to the available irrigation stream or 3.33 cubic feet per second.

First, determine the slope(s) of the hydraulic gradient in the ditches. This is the difference between the vertical interval (vi) between levees and the head (h) required on the control structure divided by the horizontal distance between levees (l) or,

$$s \quad \frac{vi - h}{l} = \frac{0.2 \text{ ft} - 0.1 \text{ ft}}{264 \text{ ft}} = 0.000375 \text{ ft per ft}$$

The design of the ditch or ditches is:

Depth, d	=	1.7 ft
Bottom, b	=	0, V-type
Side slopes	=	2 to 1
Area A	=	5.78 sq ft
Hydraulic radius, r	=	0.76
Roughness coefficient, n	=	0.04
Slope, s	=	0.000375 ft per ft
Velocity, v	=	0.60 fs
Capacity, Q	=	3.47 cfs (satisfactory)

Sample calculation 4.--Designing contour-levee irrigation and drainage system for rice irrigation

Given:

A 60-acre field of rice (A)..................	A = 60 acres
Available stream size = 2,400 gpm...........	= 5.35 cfs
Available water holding capacity of soil at root zone depth (18 in.)..................	= 3.6 in.
Saturated moisture capacity of soil at root zone depth................................	= 7.35 in.
Permeability of restricting layer...........	= 0.002 in. per hr
Net depth of application (from irrigation guide)..	F_n = 1.8 in.
Depth of flood..............................	= 3 in.
Maximum time allowable for one irrigation...	f = 6 days
Hours of operation (continuous).............	h = 24 hr
Soil intake characteristics.................	See figure 6-3
Peak-period consumptive-use rate............	u = 0.3 in. per day
Vertical interval between levees............	vi = 2.4 in.

Find:

Minimum required stream per acre, q
Maximum size of basin
Required number of basins
Time required for one irrigation
Application efficiency
Irrigation ditch sizes
Drainage requirements
Turnout and culvert sizes
Control structure dimensions
Height of levees

Procedure:

Moisture control for germination.--Using figure 6-3, find the time (T_n) required for the net depth of application (F_n = 1.8 in.) to infiltrate the soil. T_n is 345 minutes.

Using figure 6-3, and allowing one-fourth of T_n , or 86 minutes, to cover one basin, find the average depth of water that infiltrates the soil during this period. This depth is 0.62 inch at the average time $\frac{86}{2}$ or 43 min.

Average depth of water in surface storage at the end of $T_n/4$:

$$1/2 \text{ vi } (1/2(2.4)) = 1.2 \text{ in.}$$

Minimum required stream size per acre (q):

$$q = \frac{(0.62 \text{ in.} + 1.2 \text{ in.})\, 60}{86 \text{ min}} = 1.27 \text{ acre-in. per hr}$$
$$= 1.27 \text{ cfs per acre}$$

Maximum size of basin:

$$\frac{\text{Available stream size}}{\text{Minimum stream size per acre (q)}} = \frac{5.35 \text{ cfs}}{1.27 \text{ cfs per acre}} = 4.21 \text{ acres}$$

$$\text{Required number of basins} = \frac{60 \text{ acres}}{4.21} = 14.25$$

Thus the 60-acre field is divided into 15 basins of 4 acres each. Minimum-size stream for a 4-acre basin

$$q = 4 \text{ acres} \times 1.27 \text{ acre-in. per hr} = 5.08 \text{ acre-in. per hr}$$
$$= 5.08 \text{ cfs}$$

The available stream size of 5.35 cubic feet per second exceeds the minimum and is used.

The average intake opportunity time for one basin is equal to average of the time at the lower edge (345 min + 86 min = 431 min) and at the upper edge (345 min), or 388 minutes.

In figure 6-3 find the average depth of application at time equal to 388 minutes. This is 1.95 inches. Check to see if the inflow stream (Q = 5.35 cfs) will irrigate the entire area within the allowable time of f = 6 days.

The total volume of water required per basin for the average depth of application is 4 acres x 1.95 inches or 7.8 acre-inches.

The volume of water required for surface storage in one basin is 4 acres x 1.2 inches or 4.8 acre-inches. For a series of five basins, the surface storage volume that may be reused by draining to a lower basin depends on the arrangement of basins, sequence of irrigation, and loss by deep percolation.

Assume that the 1.2 inches required to cover a basin in a series of five basins is available for reuse from three of the five basins. Then the total storage required is 4 acres x 1.2 inches x 2 basins or 9.6 acre-inches.

Time required to fill one basin:

$$\frac{7.8 \text{ acre-in.} + 4.8 \text{ acre-in.}}{5.35 \text{ acre-in. per hr}} = 2.36 \text{ hr}$$

Time required to fill a series of five basins:

$$\frac{5(7.8 \text{ acre-in.}) + 9.6 \text{ acre-in.}}{5.35 \text{ acre-in. per hr}} = 9.08 \text{ hr}$$

Minimum time required to fill the three series of five basins is

3 x 9.08 hr = 27.3 hr or 1.13 days

As in the preceding example, the actual time required to complete the irrigation of a series of basins and the entire field depends on management of the drained water. The first basin in a series of five basins is ready to drain of surface storage 7.2 hours after water is turned into the series. To complete the irrigation of all 15 basins takes about 33 hours--well within the 6-day period available.

Determine the field application efficiency in percent (E):

$$E = \frac{\text{Volume needed to refill soil x 100}}{\text{Volume actually applied}}$$

The volume needed to fill the soil in one basin is

4 acres x 1.8 in. or 7.2 acre-in.

Efficiency when a series of five basins (20 acres) is irrigated:

$$E = \frac{(5 \times 7.2 \text{ acre-in.}) \times 100}{(5 \times 7.8 \text{ acre-in.}) + (9.6 \text{ acre-in.})} = 74 \text{ percent}$$

This field application efficiency applies to the entire 60-acre field.

Flooding.--Find the time required for depletion of one-half the available soil moisture:

$$\frac{1/2 \times 3.6 \text{ in.} \times 24 \text{ hr}}{0.3 \text{ in. per day}} = 144 \text{ hr}$$

Find the depth of application required to produce a 3-inch flood over the design area:

Depth required to saturate the soil....................	=	7.35 in.
One-half vertical interval between levees..............	=	1.20 in.
Deep percolation losses (144 hr x 0.002 in. per hr)....	=	0.29 in.
Depth of flood...	=	3.00 in.
Total application....................................	=	11.84 in.

Find the minimum required irrigation stream:

$$Q = \frac{60 \text{ acres} \times 11.84 \text{ in.}}{144 \text{ hr}} = 4.93 \text{ acre-in. per hr} = 4.93 \text{ cfs}$$

The available irrigation stream (5.35 cfs) exceeds the minimum and will be used.

Find the time required to flood the entire field:

$$\frac{60 \text{ acres} \times 11.84 \text{ in.}}{24 \times 5.35 \text{ acre-in. per hr}} = 5.53 \text{ days}$$

The time required is within the allowable time, f = 6 days.

Maintaining the flood.--Find the minimum irrigation stream required to maintain the flood:

$$Q = 60 \text{ acres} \left(\frac{0.3 \text{ in. per day}}{24 \text{ hr}} + 0.002 \text{ in. per hr}\right)$$
$$= 0.87 \text{ acre-in. per hr}$$
$$= 0.87 \text{ cfs}$$

Irrigation ditch design

The required capacity of the irrigation field ditch shown in section B-B, figure 6-5, is equal to the available stream size or 5.35 cubic feet per second. A ditch with a bottom width of 1 foot, a depth of 2.6 feet,

side slopes of 1-1/2 to 1, on a hydraulic gradient of 0.000125 foot per foot, and having an "n" value of 0.045 has a capacity of 5.38 cubic feet per second, thus meeting this requirement.

Drainage requirements

The drainage requirements, ditch sizes and capacities, are the same as those shown in sample calculation 3.

Turnout and culvert size

The required capacity of turnouts and culverts must be equal to the available irrigation stream or 5.35 cubic feet per second. Sizes are determined by the formula, $Q = Ca \sqrt{2gh}$.

Try using a 21-inch concrete pipe, 10 feet long, with a square-cornered entrance operating under a head of 0.12 foot. The computation becomes:

$$Q = 0.80 \times 2.405 \sqrt{2 \times 32.2 \times 0.12}$$
$$= 5.35 \text{ cfs (satisfactory)}$$

Interior irrigation ditches and drainageways

The required capacity of the combined irrigation ditches and drainageways shown in sections C-C and D-D of figure 6-5 must be equal to the available irrigation stream or 5.35 cubic feet per second.

First, determine the slope(s) of the hydraulic gradient in the ditches. This is the difference between the vertical interval (vi) between levees and the head (h) required on the control structure divided by the horizontal distance between levees (l) or,

$$s = \frac{vi - h}{l} = \frac{0.2 \text{ ft} - 0.12 \text{ ft}}{264 \text{ ft}} = 0.000303 \text{ ft per ft}$$

The design of the ditch or ditches is:

Depth, d	= 2.1 ft
Bottom, b	= 0, V-type
Side slopes	= 2 to 1
Area, A	= 8.82 sq ft
Hydraulic radius, r	= 0.939
Roughness coefficient, n	= 0.040
Slope, s	= 0.000303 ft per ft
Velocity, v	= 0.621 cs
Capacity, Q	= 5.48 cfs (satisfactory)

Control structure dimensions

For rice and other close-growing crops, the water level in each basin is often controlled by a weir placed in the levee along the lower side of the basin. These weir structures are usually made of sheet metal or some other suitable material and are located near an access road for convenience. They are generally designed to operate under a head of 0.2 to 0.25 foot. When these structures are used, the operating head must be considered in determining the height of the levees.

The weirs are made of sheet metal and are designed to have a capacity equal to the available stream capacity or 5.35 cubic feet per second. The formula for determining weir dimensions is:

$$Q = CLH^{3/2} \text{ or } H = \left(\frac{Q}{CL}\right)^{2/3}$$

With the value of C = 3.2, try crest length L = 14 feet and solve for the operating head:

$$H = \left(\frac{5.35}{3.2 \times 14}\right)^{2/3} = 0.24 \text{ ft (satisfactory)}$$

<u>Height of levees</u>

Vertical interval between levees..................	0.20 ft
Depth of flood (3 in.)............................	.25 ft
Head on weir control structure....................	.24 ft
Freeboard provided................................	.30 ft
Allowance for settlement..........................	.30 ft
Constructed height...........................	1.29 ft
say	1.3 ft

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